Coral cores from the Flower Gardens

A new tool for studying climate

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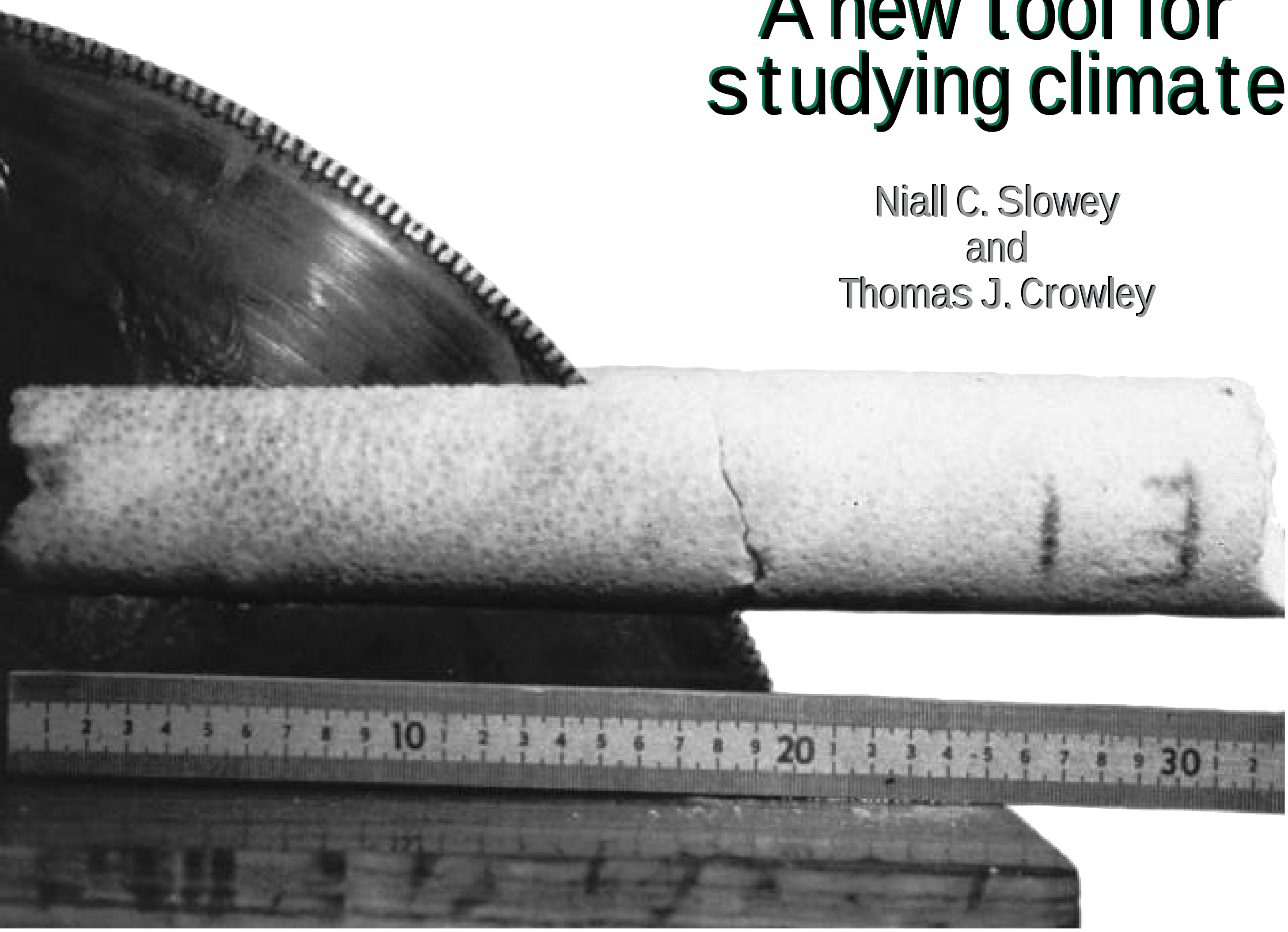


A circular saw is used to cut slabs from a coral core. The slab will be x-rayed to reveal annual bands which preserve information about past climates. (Photo by Ken Deslarzes)

Reef corals have proven to be sensitive monitors of the marine environment. The growth rate and chemical composition of their skeletons preserve a detailed history of past environmental conditions. At Texas A&M, we are studying how climate change related to variability in the atmospheric circulation of the extratropical Northern Hemisphere is reflected by corals living in the Flower Garden Banks National Marine Sanctuary in the northwest Gulf of Mexico (See “Down under…out yonder,” this issue).

Yearly fluctuations in climatic and oceanic conditions associated with the El Niño/Southern Oscillation phenomenon are known for their impact on the fisheries, marine life, and weather of the equatorial Pacific and other tropical regions.

Though less familiar, significant fluctuations in the climate of the mid- and high-latitude regions also occur between periods of years and decades. A shift in the atmospheric circulation of the extratropical Northern Hemisphere during the late 1950s affected the severity of winters and influenced human activities such as agriculture and fishing in broad areas of North America, the North Atlantic, and Europe. The Gulf of Mexico and southeastern United States are extremely sensitive to such climate variability, but little is known about its impact on the gulf's marine environment.

Significant changes in the region's climatic elements do occur, including variations in air temperature, rainfall, passage of atmospheric fronts, and strength and direction of surface winds. It is likely that the marine environment of the Gulf of Mexico is affected by this, with potentially great economic and environmental consequences. For example, the gulf and its coastal areas yield about 40% of the total commercial fisheries landings in the United States and well over 100 million fish are caught each year for recreation. Citrus farming and other forms of climate-sensitive agriculture are important to regional economies. Furthermore, the environment shelters numerous species of migratory birds and other animals, including reef corals and endangered species of turtles and marine mammals. Other regions of the Northern Hemisphere may also be affected by extra-tropical climate variability in different but equally significant ways.

We want to develop long proxy records of past interannual and interdecadal climate fluctuations and determine how they affected the Gulf of Mexico region. This historical perspective is valuable because it provides insight into climate change on the socially relevant time scale of years to centuries. In this way, we hope to contribute to efforts to recognize and anticipate future climate change and develop sound policies for managing marine resources.

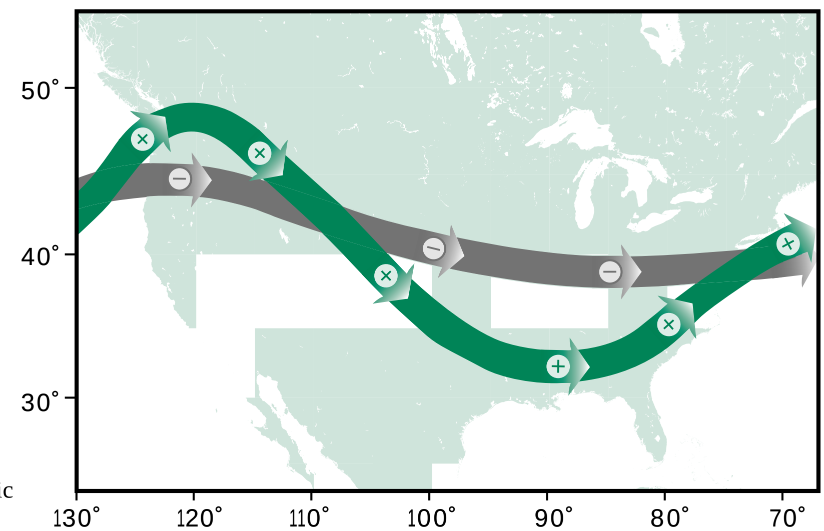
"Northers" explained

The atmospheric circulation of the extratropical Northern Hemisphere displays several preferred patterns of interannual and interdecadal variability. The most prominent is called the Pacific/North American (PNA) teleconnection because it is characterized by coincident changes in the heights of mid-tropospheric air pressure levels which extend from the central Pacific to eastern North America.

The pattern has two extreme phases. A positive PNA index value corresponds to an expanded ridge of high atmospheric pressure over western North America and deepened troughs of low atmospheric pressure over the Aleutian Islands and the southeast United States, resulting in a north-south (meridional) oriented flow of air over North America. A negative PNA index value corresponds to east-west (zonal) oriented flow.

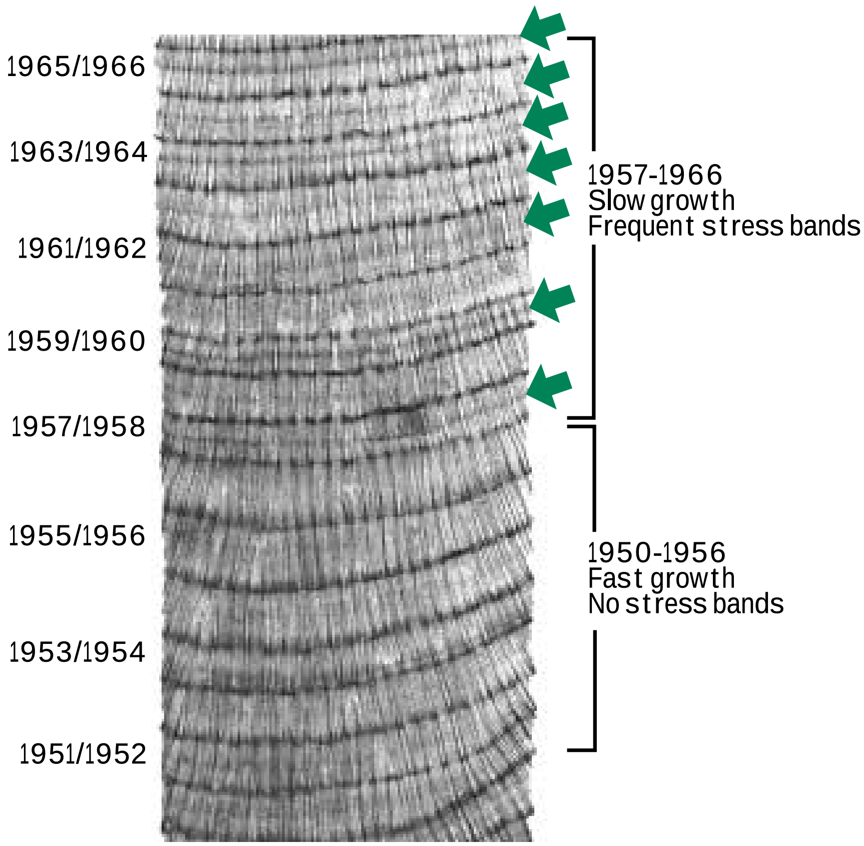
The winter climate of the Gulf of Mexico and southeastern United States is extremely sensitive to shifts between the two phases of the PNA pattern. Indeed, changes in the region's climate are used to characterize the PNA pattern itself.

The prevailing winter climatic regime is intimately linked to the minimum temperatures associated with fronts and the frequency of frontal passage. The presence of humid subtropical air from the Gulf of Mexico generally results in relatively warm winters. On the other hand, the passage of fronts to the region from the open interior of North America can bring very cold and dry Arctic air from Canada, causing extremely low minimum air temperatures, a phenomenon locally known as a "norther" or "blue norther." As a result, the gulf coast of the southeastern United States experiences



Top: *Steve Gittings, manager of the Flower Gardens National Marine Sanctuary, and Dick Zingula, a retired Shell Oil employee, examine long cores of coral skeletal material raised only moments earlier.*

Bottom: *When the PNA index has a positive (+) value, the jet stream and thus the flow of air over North America has a meridional or north-south orientation, bringing cold conditions from Canada, called "northers," to the gulf region. When the PNA index has a negative (-) value, the jet stream has a zonal or east-west orientation. (Redrawn from Leathers and Palecki, 1992)*



An x-ray of* Montastrea annularis *coral skeletal material from the Flower Garden Banks shows distinct couplets of high- and low-density annual bands. High-density bands form during the summer. To find the age of each couplet we count back from the recently deposited colony surface toward older skeletal material. The distance between density bands reveals annual growth rates. Stress bands, marked by the green arrows, are high-density bands that form when corals are subject to environmental stress.

the coldest winters of any locality in the world at the same latitude and elevation, and its average winter temperature has varied by 10°C or more over the last several decades.

Corals weather environmental change

Corals are sensitive monitors of the marine environment. Their calcium carbonate skeletal material preserves a detailed record of past environmental conditions which can be used to reconstruct the history of climate variability and understand its impact on the marine environment. We focus upon two aspects of coral skeletons to learn about the climate of the past—their density bands and the proportions of the isotopes of oxygen they contain.

Seasonal changes in environmental factors, particularly water temperature, cause variations in skeletal extension, density, and calcification, resulting in the formation of distinct pairs of high- and low-density annual bands in certain coral species. High-density bands may also form on a sub-annual basis in response to winter cold-water stress. Annual bands allow the precise age and growth rate of various portions of the coral to be determined. Changes in growth rate reflect changes in environmental conditions while stress bands indicate times when particularly extreme conditions existed. Fluctuations in the stable oxygen isotopic composition ($^{18}O/^{16}O$ ratio) of a coral skeleton reflect changes in the temperature and isotopic composition of the water in which the coral grew.

Corals grow rapidly enough that many samples can be taken from each annual band for isotopic analysis, allowing a precise record of environmental conditions to be reconstructed for nearly each month in a given year. The record obtained from a single long-lived coral can span several centuries.

Investigations of the growth and isotopic compositions of corals in the equatorial Pacific have demonstrated that they provide an invaluable historical perspective on climatically controlled fluctuations of sea-surface temperature and rainfall there. We use records of past environmental change preserved in the corals living in the Gulf of Mexico to reconstruct the history of past interannual and interdecadal changes in the PNA pattern. Features of the coral reefs at the Flower Garden Banks make them almost ideally suited for this purpose.

The banks are the northernmost tropical reefs on the Atlantic continental shelf. They are located 180 kilometers off the Texas-Louisiana coast at the edge of the shelf (27.9°N, 93.7°W) where sea-surface temperatures range seasonally from about 18° to 30°C. The reef crests, about 20-26 meters deep, are dominated by *Montastrea*, *Diploria*, and *Porities* species of corals. The geographic location of the Flower Gardens is sensitive to PNA pattern-related changes in climate. Moreover, while most coral reefs are located in nearshore waters, the Flower Garden Banks are located at the edge of the Texas-Louisiana continental shelf. They are among the only reefs that grow in and preserve a record of typical open-ocean conditions in the Gulf of Mexico. A coralline isotopic record that is not influenced by local coastal processes is necessary to clearly relate changes in the near-surface hydrographic conditions (predominantly temperature) of the gulf caused by seasonal variation and changes in the PNA pattern. The striking correspondence between interdecadal changes in coral growth rates and the PNA pattern during the past century demonstrates the monitoring potential of Flower-Garden corals.

Diving for density bands

To study the growth rate of a coral, divers first collect cores of skeletal material using a drill (see cover). We then cut slabs from the cores in the laboratory and x-ray them so that the coral's density bands can be studied and the material can be sub-sampled for stable isotope analysis.

The growth rates of sixteen coral colonies of *Montastrea annularis* living at the Flower Gardens were reported by Harold Hudson and Daniel Robbin and by Kenneth Deslarzes. They found that average annual growth rates of these corals display significant decadal-scale variations. The growth rate was 7.9 millimeters per year (mm/yr) from 1888 to 1907, it increased to 8.9 mm/yr from 1907 to 1957 and then declined to 7.2mm/yr fr om 1957 to 1979. The growth rate increased again to 9.0 mm/ yr in 1989, the last year for which data exists. Richard Dodge and Judy Lang suggested the abrupt, enigmatic decline in coral growth that occurred during 1957 was due to local variations in water temperature or outflow from the Atchafalaya River. We favor the temperature explanation because it fits well into the context of regional and global-scale climate change.

Things were tough all over

Changes in coral growth rate correspond closely to changes in winter air temperatures along the Gulf of Mexico coast. What is the relationship between the two? Water temperatures less than 18°C generally limit the development of tropical coral reefs and temperatures less than 16°C are often lethal. Temperatures at the Flower Gardens approach these limits during winter, so the physiology and growth of corals there should be quite sensitive to variations in winter temperature. The passage of fronts during winter can bring cold, dry Arctic air and low air temperatures to the region. These fronts cool the waters of the northern Gulf of Mexico and we believe this stresses the corals and stunts their winter growth.

In the late 1950s the winter climate shifted significantly toward colder winters. This shift is displayed by the PNA pattern index and is clearly reflected by the abrupt decline in coral growth at the Flower Gardens and the presence of stress bands in the corals. The wintertime PNA index shifted from negative to positive values at this time. Jeffrey Rogers and Robert Rohli observed that no major Florida citrus freezes occurred during the decade prior to winter of 1956/57, while they occurred often from 1957/58 to the present.

The shift from negative to positive values of the PNA index corresponds to a shift from a zonal (west-east) orientation of the jet stream and air flow over North America to a more meridional (north-south) orientation. The PNA pattern is strongest during winter so a meridional orientation allows cold, dry Arctic air to reach south to the Gulf of Mexico. Thus, climatic changes in the southeast United States are related to large-scale changes in the extratropical Northern Hemisphere circulation associated with the PNA pattern.

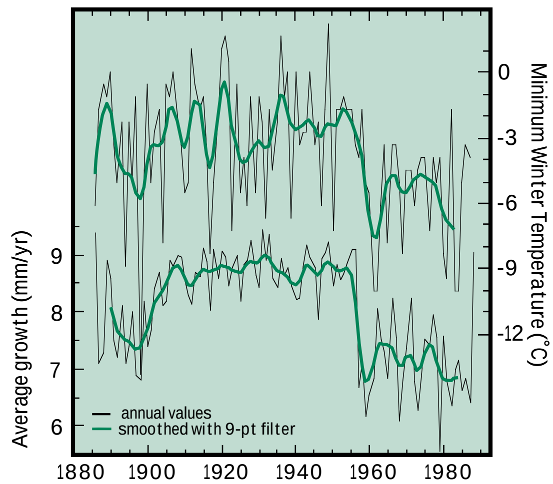
Data for calculating the PNA pattern index comes from a global-scale data collection network which has existed only since 1946. We believe that coral growth records from the Flower Gardens can provide valuable information about fluctuations in the PNA pattern that occurred prior to the development of this network. For example, existing coral and temperature records extend into the 1800s. Both coral growth and winter temperatures were relatively low from the late 1880s to the first decade of the twentieth century, suggesting that the PNA pattern and the climate during that period were like those which prevailed from the 1960s to the present. Other evidence supports this interpretation, including low winter temperatures throughout the southeast United States during both periods, as well as the tracks of winter storms across North America and documented freeze damage to citrus crops and other agricultural commodities.

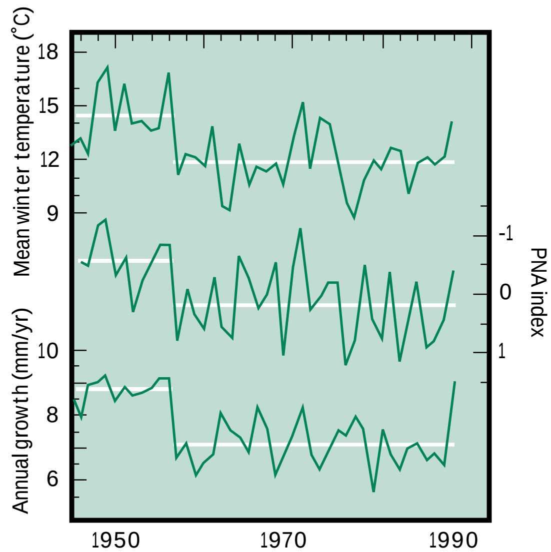
Five centuries of weather data

Working with members of National Oceanic and Atmospheric Association's Flower Garden Banks National Marine Sanctuary program lead by Stephen Gittings, we recently collected cores of skeletal material from several large *Montastrea* and *Siderastrea* corals that potentially preserve climate records nearly five centuries long! We are in the process of measuring the growth rates and stable isotopic composition of these corals to obtain long, high-resolution estimates of how environmental conditions at the Flower Gardens changed through time. This information will allow us to describe the temporal nature of climate variability in the northwestern Gulf of Mexico and the PNA pattern to an extent not otherwise possible, and to examine its relationship to other climate phenomena. ❂

Suggested further reading

Slowey, Niall and Thomas Crowley, 1995: Interdecadal variability of Northern Hemisphere circulation recorded by Gulf of Mexico corals. *Geophysical Research Letters*. 22, 2345-2348.





Top: Interdecadal changes in the average growth rates of* Montastrea annularis *coral at the Flower Gardens during the past century correspond closely with changes in minimum winter air temperature and the average winter air temperature (not shown) at New Orleans. Data sources: Hudson and Robin 1980, Deslarzes 1992, U.S. Weather Bureau and the Department of Commerce.

Bottom: Effects of the late 1950s shift in Northern Hemisphere circulation from a more zonal to a more meridional pattern are evident in the growth rates of* Montastrea annularis *coral at the Flower Gardens, the average winter air temperatures at New Orleans, and the average winter PNA pattern index. White lines show average values for indicated time span. PNA index data exist only after 1946. The index is calculated from monthly average 500-millibar (a unit of atmospheric pressure) heights measured over the the southeast United States, the Rocky Mountains and the central North Pacific.